Module 2: Fundamentals of Erosion & Stormwater Runoff

2a. Overview of the Fundamentals of Erosion and Runoff

Goal

Once we can better understand the forces which cause erosion and runoff, only then can we begin to minimize the negative results.

This module provides the some scientific foundation for understanding erosion and sediment control (ESC) in Virginia, and the consequences of ineffective control on our natural waterways and downstream properties. This module defines what is erosion is and how it occurs. Also discussed here is how erosion and sedimentation causes impacts on the environment, society as a whole, and economic impacts which we don't often realize which is the basis for the VESCP.

2b. Erosion Defined

Soil erosion is defined as the removal of the land surface by erosive forces such as water, wind, ice, and gravity.

Erosion processes carry away soil particles from one location and deposit them on another location. Erosion is an important contributor to landscape formation by wearing away mountains; filling valleys; and creating sandbars, islands and coastal planes. We refer to this as geologic erosion. Erosion is a natural process, but in many places it is accelerated by human land activities that disturb the soil.

Bryce Canyon (UT)

Geologic erosion accounts for 30% of total sediment production, accelerated erosion accounts for 70%.

As we discussed in Module 1, the mount of sediment that leaves a construction is much higher than other types of land disturbing activities largely due to the mature of the construction process and methods used on a typical construction site. When a site is stripped of vegetative ground cover the soil is susceptible to erosion in several ways.

We can generally categorize erosion in five different stages. Each stage listed below is explained from the least amount of erosion to the most damaging.

Five Stages of Soil Erosion

Raindrops impact the soil as little bombs.

Raindrop impact is the first effect of a rainstorm on the soil dislodging soil particles and splashing them into the air. The detached particles can be easily picked up by water flowing over a site and become sheet erosion

<u>Raindrop Impact</u>

Of the five types of erosion, raindrop erosion is the most significant in the erosion process. **The action of falling rain on disturbed or denuded soil is responsible for 90% or more of total soil erosion.**

Raindrop impact produces two damaging effects:

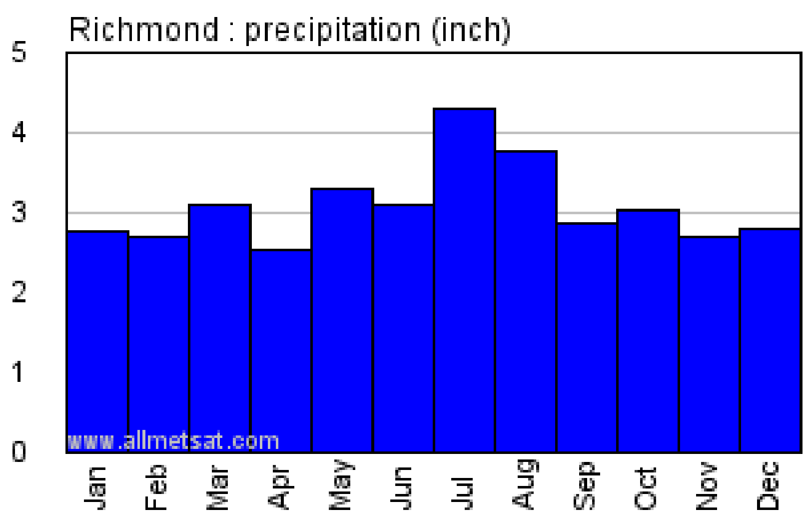
- The detachment of soil particles
- Sealing of the soil's surface

The erosive capacity of rainfall comes from the energy of its motion, or *kinetic energy*.

The magnitude of this energy is dependent on the amount and intensity of rainfall, raindrop diameter, and raindrop velocity.

All rain events contain drops of various sizes. An intense rain has a much higher proportion of large drops than a light rain. The damaging effects from rain falling as large drops in an intense thunderstorm has many times more erosive energy than rain falling as a fine drizzle over a longer period of time. In Virginia, the most erosive rains are concentrated during the months of May through September (see table below) when rainfall events occur as thunderstorms and tropical systems. ***This is also the period when land-disturbance (construction) is most active*.** Precipitation in the winter (January & December) generally falls as a finer mist with much less energy.

Precipitation Characteristics by Seasons (Richmond, VA)



Another damaging effect of raindrops is the compacting, puddling, and sealing of the soil surface. Repeated strikes churn the surface into a slurry, which seals the pore spaces in the soil preventing water infiltration. As they continue to pound the land, raindrops will also compact the bare soil, forming an almost complete seal. Even on coarse sandy soil, this action reduces the infiltration of water into the soil and leads to increased erosion and runoff.

Sediment-laden water and raindrop impact are slowly sealing the soil in this agricultural field

Sheet erosion

<u>Sheet erosion</u> is the second stage of erosion. The soil's ability to infiltrate water is exceeded & water starts to run across the surface of the soil (sheet flow). Although sheet erosion seldom detaches soil particles, the dislodged soil particles are transported by sheet flow.

Rill erosion

Rill erosion begins when shallow sheet flow begins to concentrate in low spots. As the flow changes from sheet flow to deeper flow in these low areas, the velocity and turbulence increases. The energy of this concentrated flow detaches and transports soil material, cutting tiny channels or rills that are only a few inches deep. At this stage, hand tools or other surface treatments will easily repair erosion damage.

Gully erosion

Gully erosion occurs when rills converge to form larger channels or gullies. The major difference between gully and rill erosion is size. Gullies are too large to be restored with conventional tillage equipment and usually require heavy

Channel erosion can occur in two ways. Typically you can observe vertical sides and down-cutting of the receiving channel.

1 - When gullies are not repaired in time and large volumes of water increase the size of the gully,

2 - In existing streams or drainage ways when the volume and velocity of flow destroys the structural integrity of stream beds and banks

Channel erosion

In summary, there are five stages of erosion:

Five Stages	
	• Raindrop (90%) • Sheet • Rill • Gully • Channel

Four Factors Influencing Erosion

The phases of erosion discussed above can all be correlated back to the four factors that influence erosion:

(1) Climate
(2) Ground Cover
(3) Soil properties
(4) Topography

While these factors are often interrelated, they need to be discussed individually.

(1) Climatic Factors influencing erosion include precipitation type (rain, snow, etc.); rainfall intensity and raindrop size; snow melt; and temperature extremes (freezing, excessive heat, etc.). On page 7, we discussed that raindrops are responsible for 90% of the erosion that occurs on a site and that summer storms are generally more intense and more erosive (Table 1; page 8).

Summer rains are often associated with thunderstorms with higher intensity and shorter duration

In discussing precipitation, we often refer to: amount and intensity. A two inch precipitation event in the winter is very different than a two inch precipitation event in the summer.

(2) Ground cover is perhaps the most important factors influencing erosion. As discussed earlier in this chapter, the size of raindrops and the speed by which they hit the soil are among the most important factors influencing erosion. Ground cover such as vegetation or mulches slow down the speed of raindrops by intercepting them on leaves, branches, and stalks. ***The most cost effective measure in controlling erosion from a site is to preserve existing vegetation.***

Research has shown that erosion potential is directly proportional to the amount of bare soil exposed to raindrop impact. Therefore, surface cover is the most important factor for controlling erosion. ***While vegetative cover provides the best protection, the use of any surface cover material can reduce soil erosion by 90-99%.***

Effectiveness of Various Ground Covers In Preventing Soil Erosion

Type of Ground Cover	Percent Reduction
Permanent grass	99
Perennial ryegrass	95
Annual ryegrass	90
Small grains	95
Millet or Sudan grass	85
Field bromegrass	97
Grass sod	99
Hay or straw (@2 tons/acre)	98

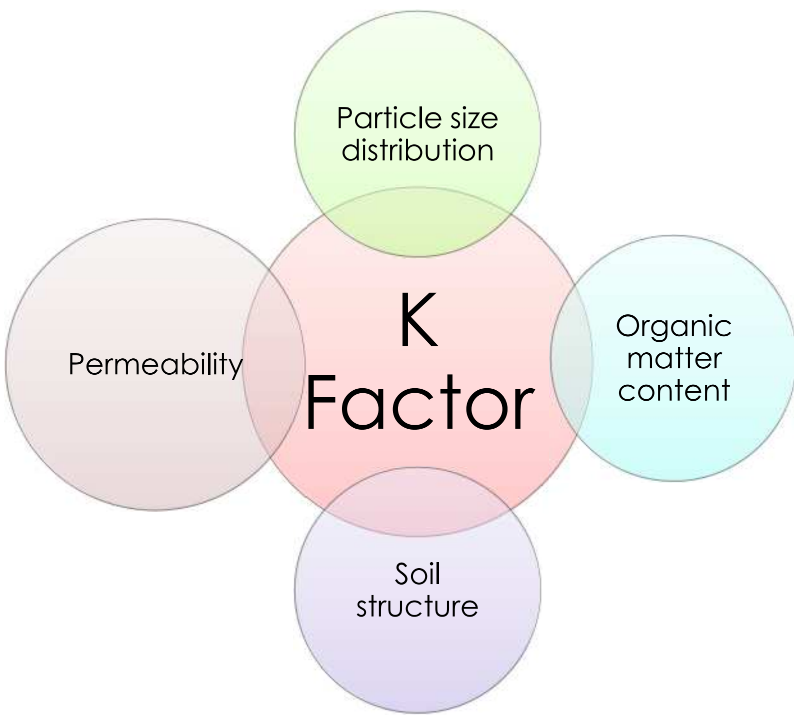
(This table compares fully established stands of groundcover with bare soil)

(3) Also important factors when looking at the erodibility of a site are **soil properties**, which include:

- soil texture (or the size of the particles in the soil),
- bulk density (or how tightly those particles are packed together),
- the percent organic matter,
- infiltration rate (the speed by which water enters the soil) and
- permeability rate (the speed by which water moves through the soil).

Under similar climatic, topographic and vegetative conditions, different soils may erode at different rates. This difference in erosion rates may be tenfold, and is caused by differences in soil characteristics. The susceptibility of a particular soil to erosion is called its **erodibility factor or K factor**. In addition to susceptibility of the soil to erosion, the soil erodibility factor (K) represents the rate of runoff.

- Soil properties used to develop a K factor for soils include:



The higher the K factor value, the more susceptible the soil is to erosion.

K factors can be grouped into three general ranges:

0.23 or lower	-	Low erodibility
0.24 to 0.36	-	Moderate erodibility
0.37 or higher	-	High erodibility

For the plan preparer/reviewer, job superintendent and inspector who are likely to be laymen in the field of soil science, the K factor is a good indicator of a soil's susceptibility to erosion. The K factor of a soil can be found in various sources, including a county soil survey, on line at the web soil survey (http://websoilsurvey. nrcs.usda.gov/app/HomePage.htm), and in Appendix 6C of the 1992 Virginia Erosion and Sediment Control Handbook.

Soils with such a high bulk density have low infiltration rates, meaning water cannot enter the soil as readily, and they become impenetrable to plant roots and plants will have a difficult time becoming established. The amount of organic matter also influences a soils bulk density as well as the cohesiveness, structure and permeability of the soil.

On a typical construction site the site is cleared, the topsoil is often stripped to expose the more stable subsoil and, with some projects, the topsoil is spread over the bare subsoil once construction has been completed. During construction, the subsoil is compacted by construction vehicles, increasing the bulk density of the soil close to that of concrete.

Common Bulk Density Measurements

Land Surface/Use	Bulk Density
Undisturbed Lands Forest & Woodlands	1.03 g/cc
Residential Neighborhoods	1.69 to 1.97 g/cc
Golf Courses - Parks Athletic Fields	1.69 to 1.97 g/cc
Concrete	2.2 g/cc

(4) Topographic features that influence site erodibility include *slope grade, slope length, slope shape and slope orientation.* The geographical location of a LDA in Virginia will have a major influence on topography.

Slope steepness or grade influences erosion in several ways. First water will flow faster as the length and angle of a slope increase. Second, there is more "splash effect" on steeper slopes. These principles are the reason for the grouping of slope gradient into three general ranges of soil erodibility (Table 2).

Relation between Slope Gradient and Erosion Hazard

Slope gradient	Erosion hazard
0-7%	Low
7-15%	Moderate
15% & over	High

With respect to ESC, slope length is defined as the distance from the point where overland flow begins to the point where it enters a well-defined channel, waterway or the point where deposition may occur because of a decrease in slope gradient.

The primary topographic considerations for erosion potential of a slope are its length and steepness. The table below provides the critical slope length for different slope gradient ranges.

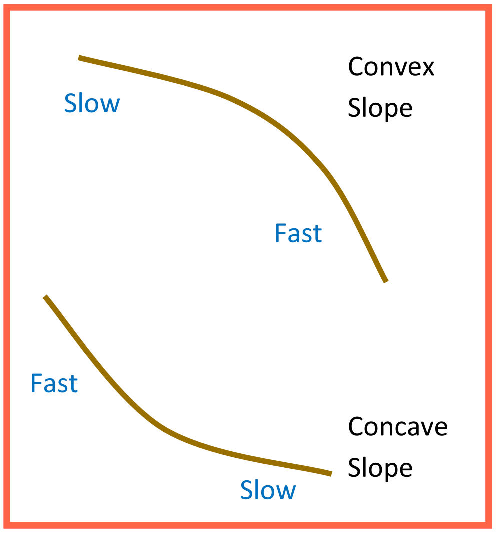
Slope Gradient and Length Combinations at Which the Erosion Hazard Will Become Critical

Slope gradient	Slope length
0-7%	300 feet (100 meters)
7-15%	150 feet (50 meters)
15% & over	75 feet (25 meters)

- Increasing slope length will increase the volume of water in the runoff.
- Slopes which exceed these parameters could be considered ***critical slopes***.
- This effect will create a point on the slope where water volume and velocity will begin to form rill and gullies without adequate ESC practices!

Slope shape also impacts erosion potential

- *Convex slopes (are slopes that are steeper at the lower end).*
- *Concave slopes (are slopes which flatten at the lower end).*



Erosion will be more on convex and less on concave slopes than what would be expected if the effect is calculated on the basis of an average grade.

Slope orientation or aspect also affects erosion. South and southwest facing slopes are usually warmer and drier because of sun exposure and exposure to warmer winds. Therefore, the vegetation on these slopes may be sparser, and establishment of new vegetation on south and southwest facing slopes is generally more difficult than northern slopes. Conversely, northern slopes are cooler, less exposed to the sun, and usually moister; therefore, it has different challenges in establishing vegetation on northern slopes.

2c. Runoff

Runoff occurs when the rate of rainfall exceeds the infiltration capacity of the soil. Runoff on unprotected soil begins a few minutes after the start of rainfall. Water on the soil surface gains energy as it begins to run down slopes as runoff.

In this early stage, the major potential for damage caused by stormwater runoff is the ability to transport loose soil particles.

The amount of runoff depends upon:

- The amount and intensity of the rainfall, and
- The character of the soil surface impacted by rainfall
- The amount and type of ground cover

Runoff initially presents itself as **sheet flow**, a shallow layer of water flowing more or less uniformly over the land. As we learned earlier, sheet erosion primarily refers to the transport of soil particles that have already been detached and suspended by raindrop impact. Runoff contains the energy that carries those suspended soil particles. Although it is sometimes difficult to estimate, total soil loss by sheet flow may be large but can be observed as muddy water. Sheet erosion can very effectively transport the particles that are kept in suspension by the action of falling raindrops on an area.

Concentrated flow starts as a result of irregularities in the soil surface such as low spots, depressions, rocks, plant stems, and roots and the depth of the sheet flow. As the volume of water increases, the velocity and turbulence also increases. Runoff concentrated in tiny rills may then expand into larger gullies, acquiring more energy to detach and to transport soil particles.

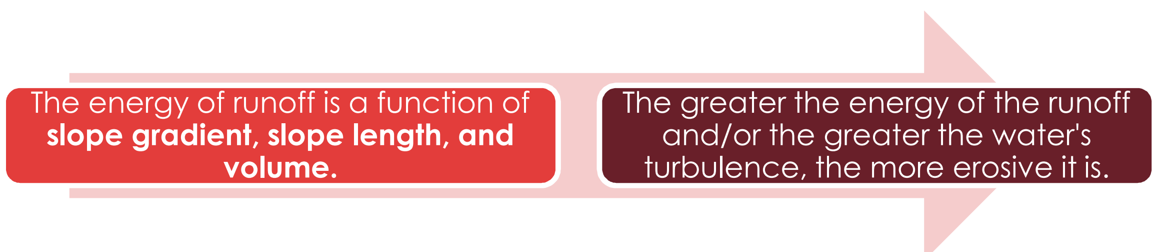
The rolling, lifting, and abrasive action of concentrated/channelized flow on the land surface results in soil detachment and leads to rill and gully erosion as discussed earlier. At first, the force of channelized flow is horizontal in the direction of the flow of water. As the velocity and turbulence of channelized flow increases, vertical currents and eddies develop that dislodge, suspend and transport soil particles. These entrained soil particles strike and abrade the soil's surface and channel beds like sandpaper, which then causes more soil particles to detach and mobilize. The turbulent flow of sediment laden water will start scouring the sides of the rills, gullies and channels.

More soils particles will become suspended in the flowing water further increasing its abrasive force. The amount of additional sediment detached by abrasive action is determined by the amount and abrasiveness of the suspended particles.

In summary, the erosive capacity of flowing water is based on its:

- Velocity
- Turbulence
- Amount and type of abrasive material conveyed by the flow
- Surface or channel roughness
- Slope gradient

As slope length and steepness increases, the depth of runoff increases and hence the velocity also increases.

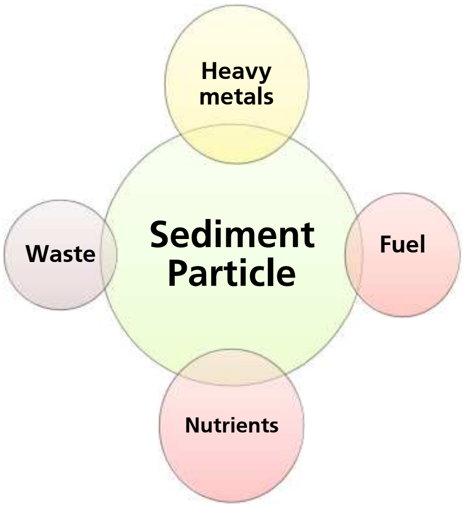


Rainfall can create stormwater runoff during construction and even post construction which ends up either onto adjacent property or in a stream, river or other natural resource.

Stormwater runoff that flows across the land surface and is not concentrated in a defined channel or pipe is considered *nonpoint source (NPS)* pollution, which is the primary cause of polluted stormwater runoff and water quality impairment.

The USEPA has ranked stormwater runoff as the second most prevalent source of water quality impairment in the nation's estuaries (agriculture is currently ranked as number one).

- **It's more than just a little dirt**
- **Sediment can have many harmful substances attached to it**



Erosion from construction sites and other disturbed areas can potentially contribute large amounts of sediment to streams. In addition to sediment, as stormwater runoff moves across the land surface, it picks up many natural and human-made pollutants, before depositing them into Virginia's waters.

Construction site erosion and runoff
Source: Chesapeake Bay Stormwater Training Partnership

Pollutants of particular interest in stormwater are excess nutrients for the following reasons:

- Nutrients are a major source of degradation in many of Virginia's water bodies.
- Elevated nutrient concentrations in stormwater runoff can stimulate excessive growth of vegetation or algae in streams, lakes, reservoirs, and estuaries (see figure below), which can diminish the quality of drinking water, recreation, and fisheries.

Algae Bloom in the James River
Source: Richmond Times-Dispatch

A Sediment Plume Entering a River
Source: ARC (2001)

When sediment and associated/attached contaminants and nutrients (Phosphorus and Nitrogen) enter waterways a cascade of issues can occur:

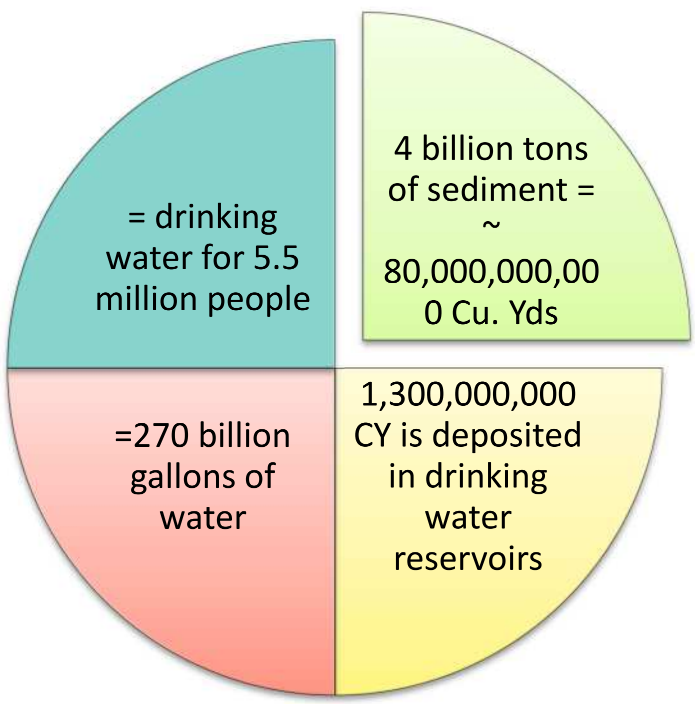
(1) Sediment shades the bottom of the waterway and weakens or kills the aquatic vegetation, which oxygenate the water and serve as cover for young fish and other aquatic organisms;
(2) Nutrients stimulate algae to grow resulting in algal blooms. This algal growth shades native aquatic vegetation and decaying algae and native vegetation depletes oxygen in the water;
(3) Sediment and contaminants in the water plugs gills of fish and other aquatic organisms thus weakening and/or killing them;
(4) Sediment settles in waterways and smothers spawning beds, oyster reefs, crab habitat, etc;
(5) Stocks of fish, oysters and crabs decline and reduce the income of commercial watermen and sports fishermen, , thereby hurting the economy of the region; and
(6) Shipping lanes, reservoirs, harbors, marinas, and other waterways may require dredging, at considerable cost (See pie chart on P. 19).

Additional impacts from erosion and sedimentation include:

- The cost to clean-up water for use as drinking water,
- The loss of fertile topsoil with a resulting loss in productivity of the land,
- Sediment deposition on land,
- In-stream erosion,
- Flooding resulting in property damage,
- Increases in turbidity in the water and habitat loss for aquatic organisms.

Quantifying Erosion and Sediment Control

It has been estimated that the total sediment production in the U.S. is 4 billion (4,000,000,000) tons per year. The average annual sewage load in the U.S. is 8,000,000 tons per year.

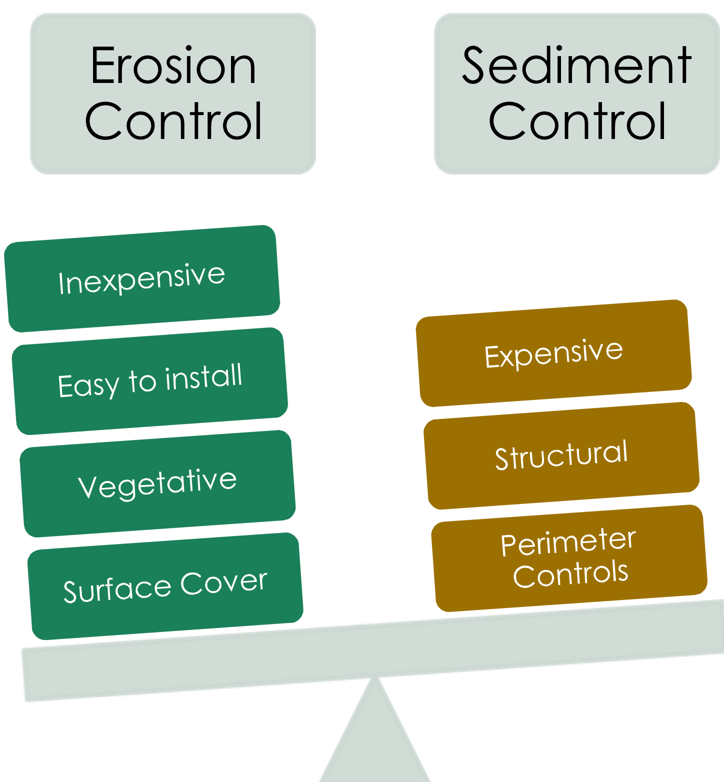


In addition to filling up reservoirs, sediment will also block shipping channels. Considering that **46%** of our imported goods come via the water ways, we can see that sediment accumulation in our shipping channels is costly to remove and maintain as well as create safety hazards to the vessels and the public.

2d. Principles of Erosion and Sediment Control

> If we can control erosion we can effectively control sediment

*The Virginia Erosion and Sediment Control Program targets accelerated erosion***.** More specifically, as the title indicates, it addresses (1) erosion control and (2) sediment control. The order, *erosion* and *sediment* control was chosen for a reason: erosion control is often considered a first line of defense, if we can control erosion efforts to control sediment can be reduced. Sediment control is considered a second line of defense, it catches the sediment from areas where erosion controls could not be installed or where they failed to work properly. Sediment control is always necessary on land disturbance projects since by definition a site can never be completely stabilized when land disturbance takes place. Erosion control is generally less costly that installing sediment control measures, and therefore erosion control generally minimizes the cost of the E&S program on a project. In addition, by trying to minimize erosion we can greatly reduce the number of sediment control measures on a site and minimize the maintenance of sediment control structures, saving additional funds.



The two principles of erosion control work together to accomplish the main goal of keeping sediment on the site.